Fractures with Major Vascular Injuries from Gunshot Wounds: Implications of Surgical Sequence

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Background: The sequence of surgical repair for penetrating extremity injuries requiring both vascular repair and fracture fixation is controversial. The optimal determination of repair order and its consequences is the purpose of this study.

Methods: A retrospective review was performed of 27 patients over a 10-year period requiring acute revascularization and fracture fixation for isolated gunshot wound injuries. Injuries to the brachial artery and the femoral and popliteal vessels with accompanying fractures requiring operative stabilization were considered. The Mangled Extremity Severity Score, surgical sequence, limb viability, fasciotomy, incidence of iatrogenic vascular repair disruption, and length of hospitalization were analyzed.

Results: There were 17 lower and 10 upper extremity injuries, with a mean Mangled Extremity Severity Score of 4.1. Fracture fixation preceded vascular repair in five cases, whereas revascularization preceded bone fixation in 22 cases. A temporary vascular shunt was used in 13 and definitive vascular repair with used in 9 patients. There were no cases of vascular repair, shunt disruption, or amputation after fracture fixation. Four of five (80%) patients with orthopedic fixation before revascularization required fasciotomies, whereas 8 of 22 (36%) patients with revascularization before fixation required fasciotomies, and this difference approached significance ($p = 0.10$). Patients with fasciotomies had a significantly longer mean length of hospitalization, 18.3 ± 8.6 days compared with 10.8 ± 8.1 days ($p = 0.03$).

Conclusion: For patients with combined injuries, priority should be given to revascularization before orthopedic fixation because of shorter hospitalization and a trend toward lower fasciotomy rates. Revascularization before fracture fixation did not result in iatrogenic disruption of the vascular repair.

Key Words: Fracture, Vascular injury, Gunshot wound, Fasciotomy, Limb salvage.

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Long bone fractures with associated vascular disruptions are a heterogeneous group of injuries.[1–3] At one end of the spectrum are injuries associated with large soft tissue defects resulting from blunt trauma or high-energy gunshot wounds (GSWs). At the other end of the spectrum are combined injuries secondary to low-energy GSWs. These low-energy GSW fractures are usually isolated insults with associated soft tissue injuries that do not require reconstruction.

Patients with mangled extremities are at high risk for infection and delayed fracture healing because of the soft tissue injury. They often have multisystem trauma and severe systemic problems as a result of the mechanism of injury. These factors contribute to many of these patients requiring primary or early secondary limb amputation.[4,5] If limb salvage is attempted, multiple limb reconstruction procedures over a period of years can result in a limb that is painful and nonfunctional.

Fractures with associated vascular disruption secondary to GSWs, however, have a much better prognosis for successful limb salvage.[6] The treatment of peripheral arterial injuries from penetrating trauma has improved dramatically over the past century. The limb salvage rate for arterial repair has improved from 64.2% in World War II[7] to 87% in the Vietnam War.[8] Recent studies report an incidence of limb salvage that can approach 100%.[9–11] Especially with low energy GSWs, the limited nature of the accompanying soft tissue insult makes these injuries due to GSW relatively homogenous compared with blunt trauma injuries.[11] Therefore, examination of the initial treatment of this subset may yield more meaningful information than analysis of the whole spectrum of combined injuries.

At the center of the debate over the initial management of these injuries is the sequence of surgical revascularization and bony stabilization. Some authors have recommended bony stabilization first to protect a subsequent vascular repair.[12–15] Stabilization after revascularization has raised concern over possible iatrogenic disruption of the vascular repair. Other authors have advocated initial revascularization, noting the effects of prolonged ischemia,[16–19] and questioned the risk of subsequent vascular disruption to a limb that has not been initially rigidly fixed.[19–22] The purpose of this study was to examine the effect of surgical order on ischemia times and the resulting clinical consequences to patients with com-

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Table 1 Anatomic Distribution, MESS, and Method of Fracture Fixation for GSW Fractures with Associated Major Vascular Injuries

	Lower Extremity Injuries	Upper Extremity Injuries	Average MESS	External Fixation	ORIF	Intramedullary Nailing
Group 1	3	2	4.2	0	1	4
Group 2	7	2	4.3	3	2	4
Group 3	6	7	4.2	1	11	1

MESS, Mangled Extremity Severity Score; ORIF, open reduction and internal fixation.
Group 1: Fracture fixation followed by vascular repair.
Group 2: Vascular repair followed by fracture fixation.
Group 3: Initial revascularization by temporary shunt then fracture fixation followed by definitive vascular repair.

bined bony and major vascular injuries resulting from gunshot wounds.

PATIENTS AND METHODS

The medical records of all patients admitted to the Ben Taub General Hospital, Houston, Texas, with peripheral vascular injuries requiring repair and associated fractures from January 1990 to December 1999 were retrospectively reviewed. The mechanism of injury was determined, and injuries resulting from mechanisms other than firearms were excluded. Injuries distal to the brachial artery and popliteal artery were not considered. Data obtained included the location of bony and vascular injuries. Injuries to other body regions were tabulated. History, physical examination, and age were used to determine the Mangled Extremity Severity Score for each patient. The use of arteriography was documented. The surgical order was determined and the method of fracture fixation and vascular repair was recorded. The occurrence of fasciotomy and the basis for that decision were elucidated. The incidence of fasciotomies in combined arterial and venous injuries was determined. The time from injury to the start of the revascularization procedure was determined. The limb status at discharge and complications were also determined.

Interval variables (e.g., length of stay and total surgical time) among the three groups were compared using one-way factorial analysis of variance (ANOVA). This included comparisons of variables between upper and lower extremity injuries. Multiple comparisons using Bonferroni correction were applied if statistical difference was identified with ANOVA. Fisher's exact test was used to compare the proportion (e.g., morbidity of fasciotomy) among the three groups. In all tests, values of $p \leq 0.05$ were considered statistically significant. Analyses were performed using SPSS statistical package 10.0 (SPSS, Inc., 2000).

RESULTS

Forty-one patients with injuries to the brachial, superficial femoral, or popliteal vessels with concomitant fractures were identified. Eleven of these resulted from injuries other than gunshot wounds, 10 blunt injuries and 1 circular saw injury in a 4-year-old. The remaining 30 patients were injured by GSWs. Two patients had unicortical bony defects that did not require operative fixation and were excluded from further consideration. One patient with a temporary shunt subsequently died because of uncorrected hemorrhagic shock during positioning for an intramedullary nail. It was noted that the shunt was not dislodged during positioning. This patient was not included in the statistical analysis, leaving a group of 27 patients. The mean age was 32 years (range, 16–53 years). Twenty-three patients sustained gunshot wounds, and four injuries were caused by shotguns. All GSWs were low energy and did not require serial debridements or subsequent soft tissue coverage procedures.

There were 11 upper extremity injuries and 16 lower extremity injuries. Two patients sustained injuries to other body regions, a scrotal laceration and a gunshot wound to the scalp, both without underlying injury. All had diminished or absent distal pulses documented on physical examination. Ankle-brachial indices were not determined. The mean Mangled Extremity Severity Score was 4.1 (range, 2–7). Fourteen of 16 patients with vascular injuries in the lower extremities underwent single-shot arteriography. Three of six upper extremity arteriograms were obtained in interventional radiology.

Fracture fixation preceded vascular repair (group 1) in five cases. Revascularization preceded orthopedic fixation in the remaining 22 cases. In nine patients, the initial revascularization was by definitive vessel repair (group 2). Two of these cases involved pulseless lower extremities distal to segmental spasm of the superficial femoral artery. Although the artery was not operatively repaired, both cases required primary repair of the femoral vein. Because a vascular exploration and repair was performed, these cases were included in the study. In 13 cases, the initial revascularization was with a temporary shunt (group 3), deferring definitive vessel repair until after the skeletal fixation.

Four skeletal injuries were stabilized by external fixation and the remainder by internal fixation, either a closed intramedullary nail (9 cases) or open reduction and internal fixation (14 cases). The differences between groups for these variables were not significant (Table 1).

Two arterial injuries were addressed by exploration alone as already discussed. Five underwent primary repair. Seven were repaired with a synthetic interposition graft. The remaining 13 were repaired with reversed, autogenous saphe-

Table 2 **Total Time of Surgery and Time from Injury to Start of Revascularization for GSW Fracture with Associated Major Vascular Injuries**

	Total Surgical Time	Time to Start of Revascularization	Injury to Surgery Start Time
Group 1	7 h 20 min	7 h 14 min	3 h 42 min
Group 2	6 h 59 min	3 h 10 min	3 h 10 min
Group 3	7 h 43 min	2 h 11 min	2 h 11 min

Group 1: Fracture fixation followed by vascular repair.
Group 2: Vascular repair followed by fracture fixation.
Group 3: Initial revascularization by temporary shunt then fracture fixation followed by definitive vascular repair.

nous vein graft. There were no iatrogenic disruptions of either definitive vascular repairs or temporary shunts by the subsequent orthopedic procedures.

The average total surgical time for all three groups was similar (p = ns). The ANOVA followed by Bonferroni correction showed that the time to start of revascularization of group 1 patients was statistically longer than those in the other two groups. A longer time from injury to the start of surgery for group 1 contributed to the longer time to start of revascularization compared with groups 2 and 3 (Table 2).

Four of five (80%) patients with orthopedic fixation before revascularization required fasciotomies (group 1). Eight of 22 (36%) patients with revascularization before fixation required fasciotomies (groups 2 and 3). Although the proportions are quite different (80% vs. 36%), Fisher's exact test did not reveal statistical difference ($p = 0.10$) between the two groups because of the small number of patients in group 1. The need for fasciotomy was determined clinically in all cases and intraoperative pressure measurements were not used. There were no cases of patients being returned to the operating room for delayed fasciotomy. The incidence of fasciotomies in combined arterial and venous injuries for the different groups is shown in Table 3, and there was no statistical correlation. There was no statistical difference in the fasciotomy rates between upper extremity injuries (27%) compared with lower extremity injuries (56%) by Fisher's exact test ($p = 0.24$). This may have been because of the small number of patients in each group. Analysis by the Mantel-Haenszel test determined that the distribution of upper extremity injuries in the three groups did not affect the overall differences in the fasciotomy rates. Patients with fasciotomies had a longer average length of hospitalization, 18.3 ± 8.6 days compared with 10.8 ± 8.1 days ($p = 0.03$, unpaired t test).

Table 3 **Incidence of Fasciotomy in Patients with Combined Arterial and Venous Injuries**

	Combined Arterial and Venous Injuries	Combined Injuries Requiring Fasciotomies
Group 1	1	1
Group 2	5	1
Group 3	2	2

Group 1: Fracture fixation followed by vascular repair.
Group 2: Vascular repair followed by fracture fixation.
Group 3: Initial revascularization by temporary shunt then fracture fixation followed by definitive vascular repair.

There were no amputations. There were two complications in group 1 including a superficial wound infection in one patient that resolved with intravenous antibiotics and a thigh hematoma requiring incision and drainage.

DISCUSSION

There are two major considerations in the determination of surgical sequence in the repair of fractures with major vascular disruptions: the effect of ischemia time on limb viability and the effect of fracture stability on the revascularization procedure. Prolonged ischemia time and the absence of collateral blood flow may necessitate expeditious revascularization. A grossly unstable fracture, conversely, may make rigid fracture fixation advisable before a vascular repair is attempted. The use of a temporary vascular shunt can obviate the need for initial rigid fixation, but the additional surgical procedure may increase total surgical time in critically injured patients. Iatrogenic disruption of either temporary or definitive revascularization by the subsequent orthopedic procedure is also possible. In addition to these considerations, the training and experience level of the surgeons factor into the treatment paradigm. Unfortunately, the consequences of surgical sequence are potentially clouded by other injuries in the blunt trauma patient with multiple injuries. The injuries caused by GSWs, however, are usually isolated injuries. The purpose of this study was to determine the perioperative consequences of surgical sequence in that group of patients.

Ashworth et al. reported on 25 patients treated for major vascular disruptions. They performed vascular repair before fracture stabilization in 8 of their patients requiring fracture fixation. The other two patients had rapid external stabilization of the fracture fragments. They did not report any cases of repair failure during fracture stabilization.[16] Treatment was determined on the basis of the tenet that "a viable limb is not always a functional limb" and that prevention of prolonged tissue ischemia should be the primary treatment objective. Therefore, reestablishing perfusion promptly was performed to lessen the effects of prolonged ischemia and subsequent reperfusion injury and felt to possibly result in better ultimate function. Unfortunately, long-term follow-up of these injuries treated at inner-city Level I trauma centers is often not possible, and the temporal relationship between ischemia times and ultimate limb function in patients with successful fracture repair and revascularization has not been reported.

The effect of mechanical stability on revascularization is a judgment decision at the time of surgery.[2,20] Certainly, relatively stable injuries can undergo vascular repair with little risk of subsequent disruption. Starr et al. reported no instances of iatrogenic disruption of either a temporary shunt or permanent repair in nine revascularization procedures followed by fracture fixation.[14] Furthermore, in a series of more than 6,000 patients with vascular injuries treated in Vietnam, Rich et al. determined that external immobilization by traction or casting provided adequate stability to protect vascular repairs in those patients with adjacent fractures.[8] Grossly unstable injuries, however, may require intermediary methods to protect the repair. One method is the use of a temporary intravascular shunt followed by skeletal stabilization before definitive vascular repair.[1,14,15,21,23] This treatment course also allows the vascular repair to be based on proper skeletal length and avoids possible redundancy in the graft or an anastomosis under tension.[24] Another method is a unilateral external fixator device.[2,15,18,23,25] Rapidly applied provisional external fixation can serve as a bridge to definitive fixation.[21] Subsequent definitive fixation can be performed at the same surgical setting or later as the patient's clinical course permits.[26]

The relatively young average age of the patients, 32 years, and the low incidence of associated injuries probably contributed greatly to successful limb salvage in our series. Also factoring into successful treatment was expeditious surgical exploration. Arteriograms were used judiciously and usually obtained in either the emergency or operating rooms, avoiding the delays of sending the patient to the radiology department. There is an acknowledged bias at our hospital toward reestablishing circulation before mechanical stability, as was performed in 23 of 28 cases. Furthermore, in this series of patients, the general surgery service demonstrated a shorter time from injury to surgery start. Fracture fixation was performed first in five cases because they were felt to have adequate collateral circulation determined by the presence of capillary refill. Fracture fixation was started with ischemia times less than 4 hours in three of these cases, and this was also noted to factor into the decision of surgical sequence. Unfortunately, these favorable circumstances did not translate to comparable times to the start of revascularization, and the group undergoing fracture fixation before revascularization had significantly longer ischemia times. The reasons for this are unclear but are possibly because of unanticipated delays in starting the operative procedures as well as intraoperative technical difficulties in fracture fixation. The possibility of these unplanned but all-too-common occurrences should be considered when determining surgical sequence.

Because long-term follow-up in our patient population is difficult, we used limb swelling necessitating fasciotomy during the initial treatment period as an indication of degree of ischemic damage. Clinical judgment was used to determine the need for fasciotomy[27,28] at our institution. Fasciotomies were performed for ischemic changes that placed the limbs at risk for compartment syndrome. Unnecessary fasciotomies were avoided, as they potentially convert a closed fracture to an open fracture and mandate subsequent wound closure or skin grafting. There was no correlation between the presence of both arterial and venous injuries and the need for fasciotomy. The increased ischemia times seen in the group of patients undergoing fracture fixation first did correlate with an increased risk for fasciotomy that approached statistical significance. The additional in-hospital care, including soft tissue coverage, for patients with fasciotomies resulted in a longer hospitalization ($p < 0.05$). Although not demonstrated in our study, there are other possible consequences of fasciotomy such as infection[29–32] or delayed fracture healing[30] that may factor into the patient's ultimate outcome.

The various methods of vascular repair performed in our series, including primary repair, synthetic graft, and reversed saphenous vein graft, were all successful. It is comforting that there were no cases of disruption of any method of revascularization by subsequent fracture fixation. Although acknowledging the potential benefits of rapid provisional external fixation before revascularization, on the basis of our data we recommend establishing limb circulation before definitive fracture fixation. The predictably shorter ischemia time causes less ischemic injury, as indicated by a lower fasciotomy rate. This in turn obviates further surgical procedures and lessens the number of days of hospitalization.

REFERENCES

1. Drost TF, Rosemurgy AS, Proctor D, Kearney RE. Outcome of treatment of combined orthopedic and arterial trauma to the lower extremity. *J Trauma.* 1989;29:1331–1334.
2. Sanders R, Swiotkowski M, Nunley J, Spiegel P. The management of fractures with soft-tissue disruptions. *J Bone Joint Surg Am.* 1993; 75:778–789.
3. Tornetta P, Olson SA. Amputation versus limb salvage. *Instr Course Lect.* 1997;46:511–518.
4. Bandyk DF. Vascular injury associated with extremity trauma. *Clin Orthop.* 1995;318:117–124.
5. Lin CH, Wei FC, Levin LS, Su JI, Yeh WL. The function outcome of lower-extremity fractures with vascular injury. *J Trauma.* 1997; 43:480–485.
6. Moniz MP, Ombrellaro MP, Stevens SL, Freeman MB, Diamond DL, Goldman MH. Concomitant orthopedic and vascular injuries as predictors for limb loss in blunt lower extremity trauma. *Am Surg.* 1997;63:24–28.
7. Debakey ME, Simeone FA. Battle injuries of the arteries in World War II: an analysis of 2,471 cases. *Am Surg.* 1946;123:534–579.
8. Rich NM, Baugh JH, Hughes CW. Acute arterial injuries in Vietnam: 1,000 cases. *J Trauma.* 1970;10:359–369.
9. Frykberg ER. Advances in the diagnosis and treatment of associated vascular injury. *J Bone Joint Surg Br.* 1990;72:116–120.
10. Pasch AR, Bishara RA, Lim LT, Meyer JP, Schuler JJ, Flanigan DP. Optimal limb salvage in penetrating civilian vascular trauma. *J Vasc Surg.* 1986;3:189–195.
11. Trooskin SZ, Sclafani S, Winfield J, et al. The management of vascular injuries of the extremity associated with civilian firearms. *Surg Gynecol Obstet.* 1993;176:350–354.
12. Bishara RA, Pasch AR, Lim LT, et al. Improved results in the treatment of civilian vascular injuries associated with fractures and dislocations. *J Vasc Surg.* 1986;3:707–711.
13. Karavias D, Korovessis P, Filos KS, Siamplis D, Petrocheilos J, Androulakis J. Major vascular lesions associated with orthopaedic injuries. *J Orthop Trauma.* 1992;6:180–185.
14. Starr AJ, Hunt JL, Reinert CM. Treatment of femur fractures with associated vascular injury. *J Trauma.* 1996;40:17–21.
15. Zinman C, Norman D, Hamoud K, Reis ND. External fixation for severe open fractures of the humerus caused by missiles. *J Orthop Trauma.* 1997;11:536–539.

16. Ashworth EM, Dalsing MC, Glover JL, Reilly MK. Lower extremity vascular trauma: a comprehensive, aggressive approach. *J Trauma.* 1988;28:329–336.
17. Howard PW, Makin GS. Lower limb fractures with associated vascular injury. *J Bone Joint Surg Br.* 1990;72:116–120.
18. Luetic V, Sosa F, Tonkovic I, et al. Military vascular injuries in Croatia. *Cardiovasc Surg.* 1993;1:3–6.
19. Rosenthal JJ, Gaspar MR, Gjerdrum TC, Newman J. Vascular injuries associated with fractures of the femur. *Arch Surg.* 1975;110:494–499.
20. Connolly J. Management of fractures associated with arterial injuries. *Am J Surg.* 1971;120:331.
21. Modrall JG, Weaver FA, Yellin AE. Diagnosis and management of penetrating vascular trauma and the injured extremity. *Emerg Med Clin North Am.* 1998;16:129–144.
22. Rich NM, Metz CW, Hutton JE, Baugh JH, Hughes CW. Internal versus external fixation of fractures with concomitant vascular injuries in Vietnam. *J Trauma.* 1971;11:463–473.
23. Hull JB. Management of gunshot fractures of the extremities. *J Trauma.* 1996;40:S193–S197.
24. Reber PU, Patel AG, Sapio NLD, Ris HB, Beck M, Kneimeyer HW. Selective use of temporary intravascular shunts in coincident vascular and orthopedic upper and lower limb trauma. *J Trauma.* 1999;47:72–75.
25. Ferraro SP, Zinar DM. Management of gunshot fractures of the tibia. *Orthop Clin North Am.* 1995;26:181–189.
26. Chervu A, Quinones-Baldrich WJ. Vascular complications in orthopaedic surgery. *Clin Orthop.* 1988;235:275–288.
27. Feliciano DV, Cruse PA, Spjut-Patrinely V, Burch JM, Mattox KL. Fasciotomy after trauma to the extremities. *Am J Surg.* 1988; 156:533–536.
28. Rollins DL, Bernhard VM, Towne JB. Fasciotomy: an appraisal of controversial issues. *Arch Surg.* 1981;116:1474–1481.
29. Blaisdell WB. In discussion of: Rollins DL, Bernhard VM, Towne JB. Fasciotomy: an appraisal of controversial issues. *Arch Surg.* 1981;116:1474–1481.
30. Rush DS, Frame SB, Bell RM, Berg EE, Kerstein MD, Haynes JL. Does open fasciotomy contribute to morbidity and mortality after acute lower extremity ischemia and revascularization? *J Vasc Surg.* 1989;10:343–350.
31. Vitale GC, Richardson JD, George SM, Miller FB. Fasciotomy for severe, blunt and penetrating trauma of the extremity. *Surg Gynecol Obstet.* 1988;166:397–401.
32. Williams AB, Luchette FA, Papaconstantinou HT, et al. The effect of early versus late fasciotomy in the management of extremity trauma. *Surgery.* 1997;122:861–866.